Modeling Progenitors and Spectra from White Dwarf Collisions: Thermonuclear and Core-Collapse Supernovae

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The past decade has seen a renaissance in observation strategies designed to detect astrophysical transients. The excitement garnered from the rapid gain in understanding of gamma-ray bursts spilled over to the transient field. Now over 20 fast-slewing telescopes exist in the worldwide astrophysics community to study transients. More importantly, large surveys with cadences designed to detect astrophysical transients have shown that the canonical picture outlining just a few classes of cosmic explosions oversimplified the diverse menagerie of objects now known as astrophysical transients. These first tantalizing observations have revived the study of failed or lost cosmic explosions: outbursts that didn't fit within the canonical supernovae.

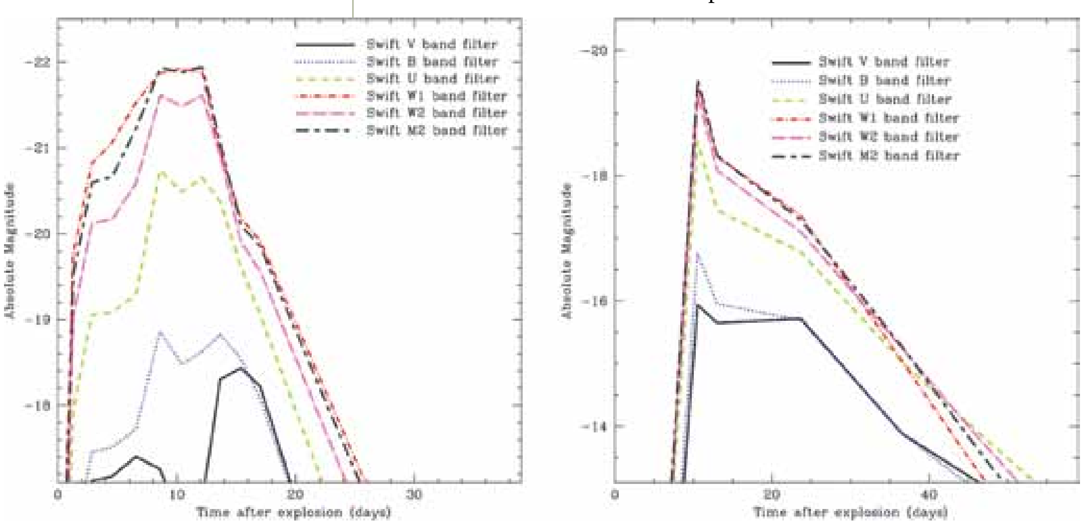

Fig. 1. Light-curves (luminosity as a function of time in astronomy magnitude units) for a range of Swift band filters [1]. A key feature of accretion-induced collapse explosions is that the ultraviolet emission is much stronger than the optical emission. The left plot shows a strong explosion exemplifying the strongest explosions produced for these objects. The right plot shows a weaker explosion. Both are plausible given the current set of error bars.

One such class of lost explosions has been the outbursts produced in the collisions or mergers of two white dwarfs. Here we discuss two types of explosions produced by such collisions: 1) the gravitational-wave-induced merger of a stellar binary consisting of two white dwarfs whose total mass exceeds the Chandrasekhar limit, and 2) the collision of two white dwarfs. If two white dwarfs merge and the combined mass of this system is above the Chandrasekhar limit, electron degeneracy pressure can no longer support the merged object and it collapses. Scientists had predicted that such a system would collapse to form a neutron star and a weak supernova explosion. But until this past year, none had been observed, or if they had been observed, they were thrown out of any published sample. However, due to broader-interest surveys in astrophysical transients, observations were reported this year of a couple potential accretion-induced collapses, as these merger-induced collapses are termed.

Figure 1 shows the first detailed light-curve calculations of the collapse of a merged double white dwarf binary system [1]. We discovered that the light curves depend very sensitively on both the surrounding medium and the exact nature of the explosion. In working with observational astronomers in the Swift consortium, we produced light curves for each of the Swift bands. The ultraviolet provides an ideal diagnostic of the supernova type, and Swift observations will be critical in identifying the class of each observed outburst. We have also worked closely with the Large Synoptic Survey Transient team and calculated light curves for likely filters for this telescope (presented at the January 2010 American Astronomical Society (AAS) meeting). With these models, we were able to rule out some of the potential accretion-induced collapse candidates, but the identification of the remaining observations as white dwarf explosions is now on much more solid ground. Accretion-induced collapse outbursts may have very strong gravitational wave signatures (strongest of any stellar collapse event) and exhibit pristine neutrino signals. As such, they are ideal transients for studying general relativity, nuclear, and particle physics. Our preliminary work places us in an ideal position to dominate this field.

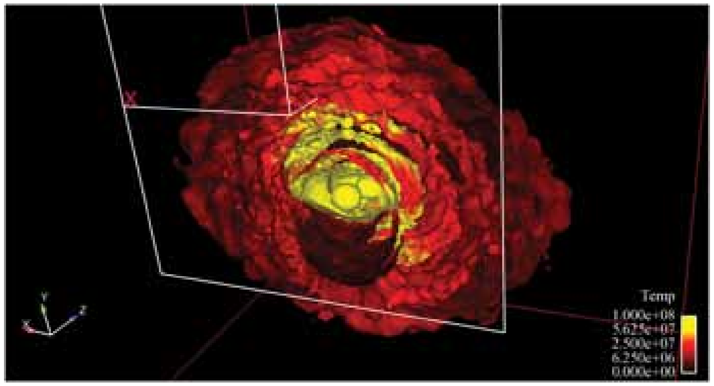

Fig. 2. Peering into the heart of two colliding white dwarfs. The color-coding denotes temperature. Shock heating can ignite a thermonuclear explosion, causing a supernova-like outburst.

With transient surveys discovering new classes of outbursts, scientists have also begun to study new ways to produce transient-like phenomena. Using LANL's SNSPH, a parallel 3D smoothed particle radiation hydration code, scientists at Arizona State University modeled the collision of two white dwarfs [2]. Figure 2 shows an image of this collision at a single point in time. In some cases, the collision is violent enough to ignite the white dwarf, driving a thermonuclear explosion. Although very different than the canonical type Ia supernovae (also known as thermonuclear supernovae), it demonstrates that thermonuclear explosions of white dwarfs can occur in a variety of manners. It may also explain a set of abnormal type Ia supernovae. Again, observations have discovered that nearly 30% of thermonuclear supernovae are not normal, and it is very possible that some of these abnormal supernovae arise from collisions.

Figure 3 shows the spectra produced by LANL's supernova light-curve effort. The LANL effort takes advantage of both codes and physics capabilities developed under the Advanced Simulation and Computing Program (ASC) and the Campaign programs at LANL, allowing this work to produce the first ever light curve (luminosity versus time) and corresponding detailed spectra (luminosity versus photon energy) using a single two-temperature radiation hydrodynamics calculation. The detailed atomic opacities used in these calculations allowed us to produce detailed spectral images. The spectra in Fig. 3 can be compared with observations of these outbursts and distinguish collision-induced thermonuclear supernovae from the more canonical type Ia supernovae. Such work is critical for the Joint Dark Energy Mission's success. The Joint Dark Energy Mission assumes that we can use type Ia supernovae as standard candles (we know the intrinsic luminosity of an object so can determine its distance based on its apparent luminosity). If objects such as these colliding white dwarfs are infiltrating our high-red-shift sample of supernovae, they may skew the resultant calculation for dark energy parameters. We have been tasked as theorists to determine diagnostics so that we can exclude these anomalous outbursts from our sample.

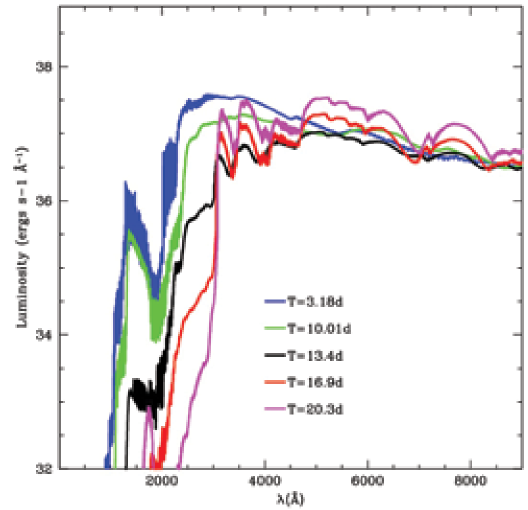

Fig. 3. Spectra from the outburst produced in the collision of two white dwarfs. These spectra were produced using the entire 14,900 group opacity data produce at LANL using the TOPS code and all the features are due to lines in the atomic physics. The more robust features can be used to distinguish these explosions from other explosions.

These failed or lost white dwarf explosions have implications for a wide range of physics and astrophysics projects from the Joint (NASA/DOE) Dark Energy Mission to the NSF Laser Interferometer Gravitational-Wave Observatory led by general relativists to nuclear physicists working on the Facility of Rare Isotope Beams and the Deep Underground Science and Engineering Lab. These initial studies, leveraging LANL's computational and physics expertise developed under ASC and the Campaigns, place LANL at the forefront of these studies, and we are in an ideal position to take our initial successes and dominate this broad-implication research.

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[1] C.L. Fryer et al., *Ap. J.* **707**, 193 (2009).
[2] C. Raskin et al., *Mon. Not. R. Astron. Soc.* **399,** L156 (2009).

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